Volume 35 June, 1949 *Number 6*

STACKS

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

MISSOURI SCHOOL OF MINES & MET. LIBRARY JUN 30 1949 PROPERTY ROLLA, MO.

THIS ISSUE

Spark Plugs
For
Internal Combustion
Engines

PUBLISHED BY
THE TEXAS COMPANY
TEXACO PETROLEUM PRODUCTS

a clean engine gives full

power

and Havoline Motor Oil keeps engines clean

Power is yours for the asking when you specify Havoline Motor Oil. The top performance of your motor is assured because Havoline keeps the engine cleaner and better lubricated – free of gummy carbon and sludge. A *clean* motor uses less gas – gives you more miles and power from every gallon. So get Havoline today – from your Texaco Dealer, *the best friend your car ever had.*

THE TEXAS COMPANY

LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

Published by
The Texas Company, 135 East 42nd Street, New York 17, N. Y.
Copyright 1949 by The Texas Company

Vol. XXXV June, 1949 No. 6

Change of Address: In reporting change of address kindly give both old and new addresses.
"The contents of 'LUBRICATION' are copyrighted and cannot be reprinted by other publications without written approval and then only provided the article is quoted exactly and credit given to THE TEXAS COMPANY."

Spark Plugs For Internal Combustion Engines

THE SPARK PLUG, although a relatively small part of a spark-ignition internal combustion engine, is far from being an insignificant item. For its size it may well be the most important component because the overall well-being of the engine is critically dependent upon the plug's satisfactory performance. Plug performance today is so superior to that of a few years ago that many users give little thought to that piece of equipment. The spark plug industry expects to manufacture an estimated 300 million plugs this year and one manufacturer, alone, will make over 100 different types.

THE heart of any spark-ignition internal combustion engine is the spark plug or "sparking" plug as termed by our English friends across the sea.

While the gasoline engine is an assemblage of many necessary components, without good spark plugs the coordinated functioning of all of these components, required for successful engine performance, would not be possible.

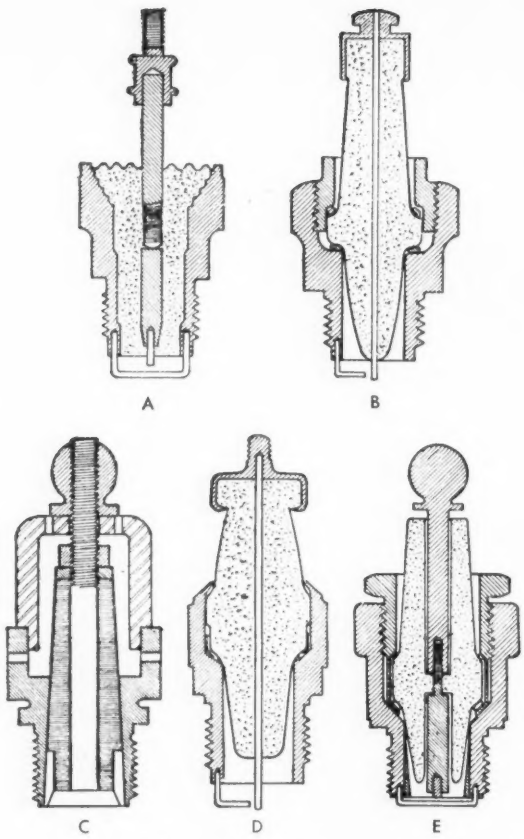
The spark plug has come a long way in the last 50 years. Its development has paralleled that of the gasoline engine as well as gasoline itself.

Not all the problems associated with the combined use of spark plugs, engines and gasoline have been solved, but it can be expected continuous improvement will be made through mutual and cooperative effort of the three industries concerned.

HISTORY

The first "commercially successful" spark-ignition internal combustion engine was invented by M. Lenoir in 1860. The spark plug used in this engine had electrodes spaced one-half inch apart, the spark timing was erratic and the engine did well to overcome its own friction. While by 1900 replaceable spark plugs, as we know them today, were commonplace, their design and construction left much to be desired. Also, because piston ring design was still in its infancy, engine compression was poor and considerable oil pumping was encountered. Both factors resulted in carbon fouling and oil wetting of spark plug electrodes and as a consequence many design variations were introduced during the early part of the century to guard against these deficiencies.

During World War I, aircraft spark plugs with porcelain and mica insulations were commonplace. In automotive practice during the same period, some steatite insulations—so-called because the mineral steatite (soapstone) was substituted for some of the more common porcelain ingredients—was used. Many other insulation materials and basic designs were put forth, mostly unsuccessful yet interesting. Figure 1 shows several types available in 1920; A was a glass insulator, forced in when molten; B was a screw bushing type which used a metal gasket for a seal—not too different from the modern two-piece construction; C had a tapered mica or steatite insulator, but was impossible to make leak-tight; D had a crimped shell which held the insulator in against a metallic gasket, forerunner of modern one-piece plugs; and E had a spun brass gland around the shoulder of the insulator to improve leak-tightness.



Courtesy of National Advisory Committee for Aeronautics

Figure 1 — Types of spark plugs available in 1920

Mica Plugs

Mica was much superior to the porcelain available in the 20's. Porcelain and glass were very susceptible to cracking and consequent electrical failure as a result of severe temperature fluctuation characteristics in aircraft engine operation. In milder operations in automobile engines however, porcelain served with fair success. Mica had better insulating properties at elevated temperature and was not so fragile, but had the objectionable characteristic of absorbing oil, moisture and fuel combustion products between the compressed mica washers.

The low thermal conductivity of mica created great difficulty in keeping plugs cool. Engine operations in the late 30's and early 40's required spark plugs that could withstand temperatures in excess of 1000°F. At such temperatures mica decomposes, losing its chemically combined water of crystallization thereby destroying its normal insulating and other desirable physical properties. Higher engine compression pressures were more sensitive to mica's adsorption of moisture, and this frequently made mandatory plug storage in heated drying cabinets. Furthermore, there was the fact that, being essentially silicates in composition, mica readily reacted with and was attacked by lead compounds from fuel combustion forming a relatively low melting-point lead silicate glass. This material, while being a fair insulator at ordinary room temperatures, is a good conductor of electricity when hot. This was a cause of mica plugs misfiring at elevated engine operating temperatures.

Nevertheless, mica served admirably up to the early 1940's at which time, due to the advent of higher powered engines and the use of increased amounts of tetraethyl lead fluid in gasoline, the use of mica in spark plug construction began to decline. Today, mica plugs are used in certain industrial engines and in smaller, air-cooled private plane engines operating on fuels containing little or no lead and where a relatively "hot" plug is recommended, such as shown in Figure 2.

Ceramics

Due to the shortcomings of mica for good spark plug performance, researchers developed superior ceramics* to replace this material. Siemens in Germany introduced sintered aluminum oxide (essentially Al_2O_3, mined in the natural state as crystalline corundum or synthesized as alumina) in the late 1920's and since then, the ceramic insulator has found widespread use. Corundum is frequently modified with small amounts of other oxides to impart certain particular characteristics such as improved electrical insulating properties, high temperature, strength, etc. Besides small quantities of magnesia and silica, often occurring in the binder, commercially available plug ceramics may also contain various mixtures of boria, beryllia, calcia, zirconia and/or thoria.

Alumina has very high mechanical strength, high electrical resistance at high temperatures, resists sudden heat shocks, has excellent heat conductivity of an entirely different order as compared with porcelain, and is resistant to corrosive attacks from lead compounds. Thermal conductivity is an important quality as it largely determines plug operating temperature; insulators with high thermal conductivity may be made with longer firing ends and, accordingly, longer electrical leakage paths. The superior resistance of alumina to attack by lead compounds is due to its chemically basic character.

Plug nose ceramics were once glazed all over with a coating having a high silica content. The firing end was glazed to retard the adherence of carbon; however, this glaze had to be abandoned

*The word "CERAMIC" is derived from the Greek word "KERAMOS" meaning "burned earth", thereby indicating its inorganic character. It is a generic term commonly associated with clays, but embraces a large number of minerals, rocks and mineral products such as clay products, pottery, china ware, glass, vitreous enamels and cements. Porcelain is one of the best known electric insulation ceramics.

on current plugs due to its susceptibility to attack by lead oxides. A glaze is retained on the outer end of the insulator to resist accumulations of moisture, dirt, etc., which can provide a conductive path and encourage flash-over. Being glazed, this part of the plug can easily be wiped clean. Figures 3 and 12 typify current, popular automotive type plugs.

PLUG TYPES

The modern spark plug must perform the same basic function as its pregenitor but usually under more trying conditions. Now their size, shape and location are very carefully considered. Although spark plugs may be very similar in overall appearance, their performance may be widely different as many built-in design features are not externally visible.

Spark plugs are made in a large variety of types and styles as, in many applications, they have to be fitted to a particular kind of engine operation. Briefly, however, they have certain general classifications which include: thread size, ranging from 10 mm to 7/8"; shielded or unshielded, the shield protecting against radio interference; thread reach, or length of thread which depends upon cylinder head thickness (in general, aluminum heads take a longer reach plug than a cast iron head); number and arrangement of ground electrodes; and heat range.

Plugs are made in two basic types of construction: one-piece and two-piece (some three-piece—steel body, center insulator and coupling nut). The two-piece design had, until recently, definite advantages, it could be disassembled to facilitate cleaning "on-the-job," and when carefully reassembled would be leak tight. Better sealing techniques have been developed in the last few years, however, so that the modern one-piece plug can be made gas tight. In certain series of plugs, either one or two-piece construction can be obtained. Although the latter usually is more expensive to purchase, some manufacturers make available replacement parts and overhaul services which enable some operators to realize an overall net savings, despite the higher initial cost. Figure 3 represents a typical one-piece spark plug; Figure 2 is a two-piece design. For any one type of operation—aircraft, stationary gas engine or automotive service, for example—plugs are graded according to their heat range; that is, the optimum operating temperature of the electrodes and core nose.

The difference between a "hot plug" and a "cold plug" is controlled by the structural design; that is, the effective heat path from the center tip to the water jacket (or to the air if it is in an air-cooled engine) is longer for the hot plug than the cold one. This difference is shown in Figure 4 which compares two automotive plugs of widely different

Courtesy of The B. G. Corporation

Figure 2 — Showing the B. G. 2-piece mica plug

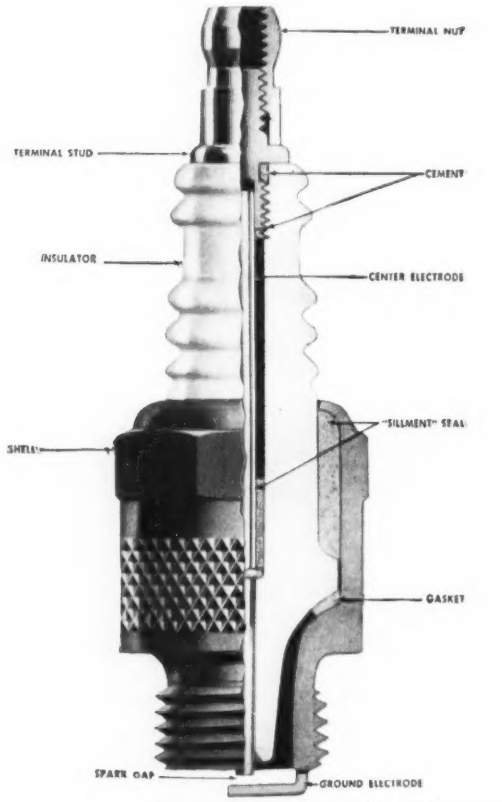
heat range. The cross-sectional area and thermal conductivity of the ceramic, and the conductivity and amount of exposure of the center electrode all control the nose temperature so that it is possible to have two plugs of identical outside dimensions and core shape with different heat ratings. Similarly the heat range of a plug may be greatly increased by providing an insulator tip as shown in Figures 14(A) and 15(A). The section or mass of the annular tip is so small that it tends to follow the temperature cycle of the cylinder, and it attains a temperature high enough at lower engine loads and speeds to inhibit against deposition of oil and the vapors of lead compounds without causing preignition at high engine output.

Attention is called to the center electrode details of aviation plugs shown in Figure 5. Note the manner in which the center electrode tips are cooled. In these designs which require maximum performance, high conductivity metals must be em-

ployed, in one case a silver core, and in the other copper with a protecting envelope of nickel alloy. These heat drains reach up into the plug ceramic a sufficient distance so that the heat discharged from the cooler ends can find ready access to the finned cylinder head and barrel.

PLUG TESTING

The determination of pre-ignition temperature may be accomplished by various means. Perhaps the most interesting is the use, in a test engine, of specially made thermocouple spark plugs which have a fine thermocouple located in or near the center electrode tip. Although these are purely research tools, data obtained by them are invaluable in the design of future plugs and engines. With a very careful placement of the fine thermocouple lead wires, their presence has no appreciable effect upon the heat rating of the plug.



Courtesy of Champion Spark Plug Company

Figure 3 — Typical 1-piece automotive plug

The best laboratory means of rating peak plug performance so far developed is in a special, overhead valve, one cylinder gasoline engine* having a displacement of 17.6 cubic inches. This is a very rigidly built research engine and is capable of operating under unit loads exceeding those developed by any commercial engine. To rate a plug installed in this engine, the power output is increased by raising the supercharge until a load is reached at which the plug goes into pre-ignition. The maximum engine output without pre-ignition, expressed as Indicated Mean Effective Pressure** is the IMEP rating of the plug; the higher the rating, the hotter the plug can operate without pre-ignition.

Figure 6 graphically shows comparative data obtained in a 17.6 engine using specially constructed "hot" and "cold" type plugs with a thermocouple embedded in each insulator tip. Notice for the hot plug that, as the load (IMEP) was increased, the plug temperature also gradually increased up to where pre-ignition occurred. Beyond that point, the temperature would very rapidly increase in a manner which could soon bring about destruction of normal plugs and other engine parts. The "cold plug," when operated over the same load range also increased in temperature; however, even at the maximum load imposed, it remained cool enough to perform satisfactorily at high output. Note that the "cold plug" is also considerably cooler at the light load condition and, if the load were to be decreased further, a condition may occur where that plug is too cold, and cold fouling may occur; this would not take place with the "hot plug" under similar light load conditions.

ELECTRODES

Although platinum is reported to have been used for spark plug electrodes as early as 1895, electrode materials for the past thirty years have almost all been made of nickel or some nickel alloy. The popularity of nickel for many years attests to the judicious selection of this material. The particular alloy varies from one plug manufacturer to the next by incorporating small amounts of other metals (chromium, barium, manganese, columbium, silicon) which enhance certain characteristics of the nickel. These alloying ingredients provide, in an economical design, maximum resistance to deterioration under the electrical discharge, a reduction in the voltage necessary to produce a spark at the gap, and reduce attack in the presence of heat and chemical reactions resulting from the combustion process. Due to the large number of controlling variables in electrode design, data obtained by various investigators frequently are contradictory, and the "best electrode" is a subject of considerable controversy.

In the aircraft spark plug field, two schools of thought exist as to the electrode design and construction; i. e., massive (thick wire) electrodes of

*Manufactured by Laboratory Equipment Corporation, Mooresville, Indiana.

**Indicated mean effective pressure is the average pressure, throughout the engine stroke, required to produce the observed indicated horsepower.

the aforementioned nickel alloys vs. fine-wire electrodes of platinum. Contrasting firing ends of these two classifications of spark plugs which are used by the commercial airlines are shown in Figure 7. Note the bi-metallic center electrode of the Champion plug.

Although considerably more costly, the fine-wire platinum type has excellent corrosion resistance and, due to the smaller size, produces a more exposed spark. Furthermore, a lower sparking potential may result, probably enhanced by the sharper edges of the fine-wire design. Fine wires have a lower heat retention and can be heated and cooled more rapidly, tending to follow the thermal fluctuations of the combustion cycle.

PLUG DEPOSITS

Analysis in a chemical laboratory of the encrustments scraped from the firing end of a spark plug can tell something of the overall engine behavior, although simpler means usually are available. Nevertheless, a typical analysis may show traces of metals such as iron, aluminum, copper, tin, etc., as engine wear progresses; silica and other minerals drawn into the engine as dust through the carburetor; carbonaceous material from the combustion of gasoline and decomposition of oil; metals and mineral oxides resulting from the additives (if any) in the decomposition of the lubricant; and lead in the form of oxides, chlorides, bromides, sulfates and combinations thereof. With average road dust and usual engine wear conditions, these sources of plug contamination are low; deposits are essentially carbon (soot) and lead compounds. For engines operating on fuels containing no tetraethyl lead, carbon usually predominates, but cases have been reported of hot-running plugs on which heavy mineral deposits were almost entirely due to decomposition of the additives in the crankcase oils.

As deposits control the spark-plug's appearance to a great extent, acquaintance with the behavior and formation of various deposits usually permits the type of operation being deduced from a visual inspection of the plug.

Satisfactory operation usually produces a smooth, light-brown core nose with, perhaps, a light, fluffy dry soot on the body which can be readily wiped off with a cloth. With unleaded petroleum fuels, the brown coloration may be due to iron compounds resulting from cylinder wear or drawn in through the carburetor as dust. The electrodes should be grey. Tetraethyl lead fluid in the gasoline may cause a greyish-yellow to brown powdery deposit on the insulator and electrodes.

Cold plug operation is usually indicated by soot deposits on the insulator and plug body which may originate from either the fuel or lubricant. A soft, fluffy carbon deposit frequently identifies fuel soot resulting from incomplete combustion. While the use of too cold a plug may be the cause, other factors such as low engine operating temperatures, worn compression rings, unsatisfactory valve performance or overly rich mixtures caused by improper carburetion or poor choke efficiency may be responsible. All mechanical factors should be checked as it cannot be expected that by going to a hotter plug 100% combustion efficiency will result. Even a plug of ideal heat range may be found coated with soot if it were checked immediately after a period of sustained idling during which normal operating temperature was not reached. To overcome this descrepancy, a plug should be checked immediately after a normal run.

Fouling from oil pumping produces a hard, shiny, sometimes wet deposit on the entire firing end of the plug. Oil remaining on the plug slowly carbonizes, becomes dry and when sufficient in amount the carbon fouling on the insulator can

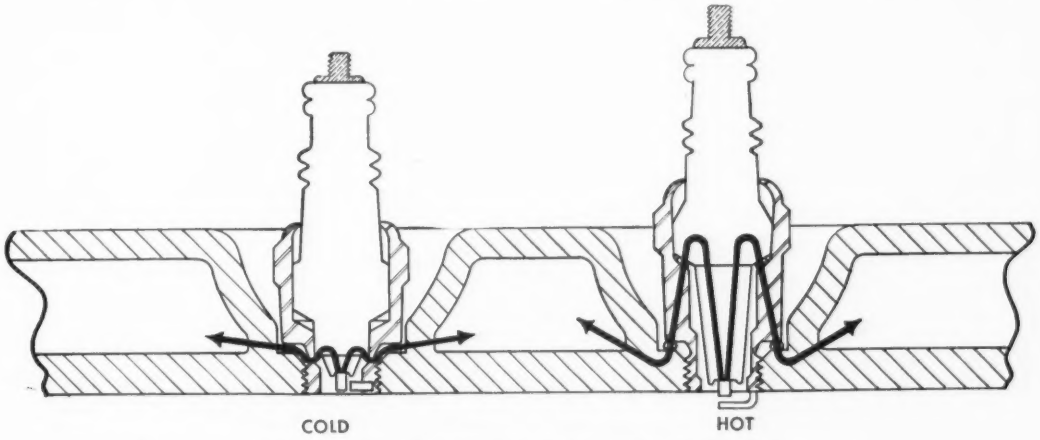
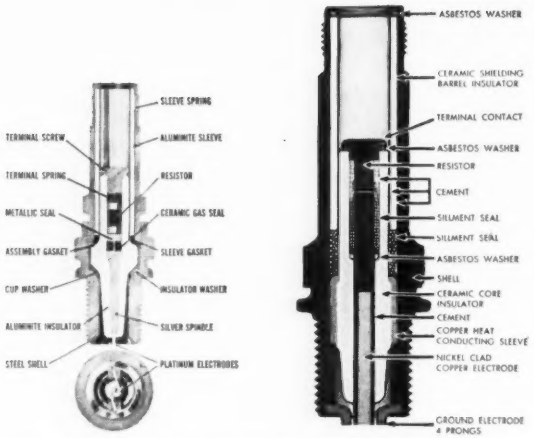


Figure 4 — Heat flow paths in "cold" and "hot" type plugs



Courtesy of Champion Spark Plug Company and The B. G. Corp.

Figure 5 — Shielded aviation plugs showing different treatment of center electrodes

make a conductive path to ground, to entirely short out the plug, or produce sporadic misfire. In this case, improved oil consumption control is obviously desirable. A temporary alternative would be a hotter plug to maintain the core nose and electrodes above the oxidation temperature of carbon.

Too hot operation may be evidenced by a dry, white or light-tan insulator while the electrodes reveal burning. The core nose may be chipped, cracked or blistered. Figure 8 shows several burned electrodes, and a plug with a chipped core nose. With leaded fuels, the core nose may be covered with a dark, shiny deposit, sometimes in the form of yellow-brown to black glossy beads, see Figure 10. A shiny appearance may signify that the ceramic temperature was so great that the deposit of lead compounds had melted, forming a fluid slag.

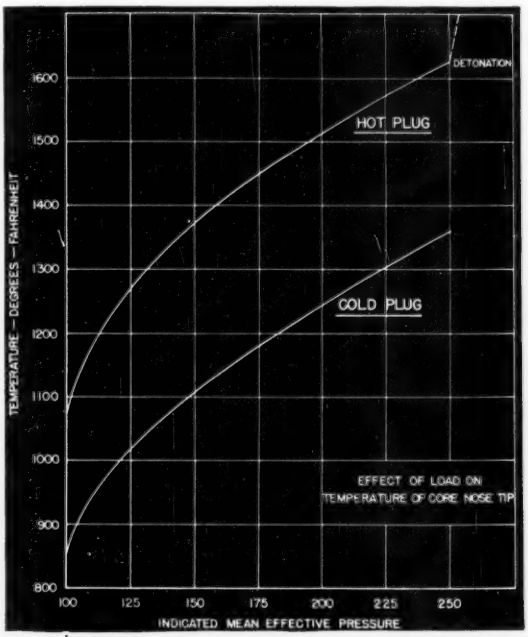
A mild condition of hot operation in automotive equipment with leaded gasoline may show no ceramic cracking, electrode erosion only to a slight extent, with a light colored dry or powdery deposit. Such a deposit, in itself, does not impair the sparking efficiency of the plug as much as it would seem. Its effect becomes appreciable only when complicated by still higher operating temperatures which could cause the deposits to melt, to become increasingly conductive to electricity, or by a subsequent excess of carbonaceous deposit, such as caused by an inoperative choke.

In the case of over-richness, especially in aircraft, it creates a reducing atmosphere in the combustion chamber which may promote a reduction of the lead compounds to metallic lead.* An example of very high temperature operation in aircraft service caused by a lean carburetor setting at a high I.M.E.P. is shown on the aircraft plug pictured in Figure 9, where the molten deposit shorted across the electrodes. In this case, chemical analysis of the deposit showed it to be essentially lead silicate which melts at 1411°F. Silica (probably airport dust) reacted with the oxides on the plug to form the silicate.

At first glance enriching the mixture with (leaded fuels) would appear to contribute a greater amount of lead products; however, this is not the case. The total amount of combustion products passing through the engine is greater, but the amount deposited normally is reduced. The controlling factor is in the oxidizing conditions existent in the combustion chamber; at lean mixture ratios there is an excess of oxygen. In such oxidizing atmosphere there is a tendency to form lead oxide; whereas in making the mixture richer, the amount of excess oxygen is reduced, thereby promoting the formation of the halide which is considerably more volatile than the oxide and, therefore, more readily volatilized out of the system.

PLUG PERFORMANCE

For best performance the plug must operate within its designed heat range and be properly seated on the gasket. If spark plugs are of the wrong type or are inefficient, the compressed gas may burn in a sluggish manner. This may result

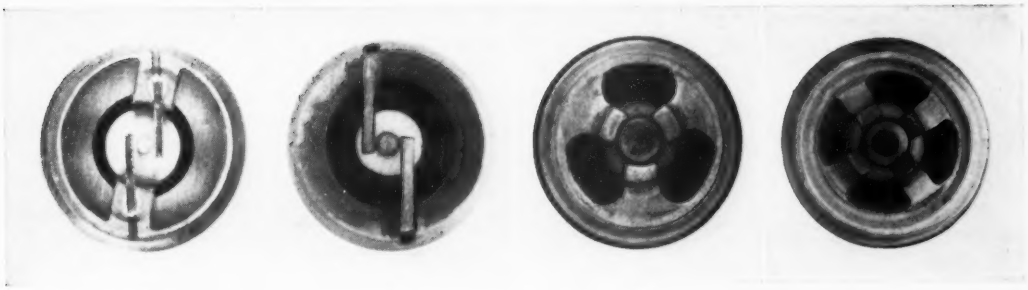


Courtesy of Champion Spark Plug Company

Figure 6 — Effect of load on temperature of spark plug core nose tip

*This chemical reaction is enhanced by the catalytic action of platinum electrodes and can be readily checked in the laboratory by heating to approximately 1200° F. in a porcelain crucible combining proportions of graphite (or lamp black) and litharge, PbO, one of the substances found in deposits resulting from combustion of leaded fuels, in accordance with the following equation:

C + 2 PbO + Δ = 2 Pb + CO_2
Carbon + litharge + heat = molten lead + carbon dioxide



A B C D

Figure 7 — Electrode arrangements for aviation spark plugs. (A) and (B) show fine wires; i.e. B. G. and A. C. types. (C) and (D) show massive type; i.e. A. C. and Champion

in incomplete combustion with only part of the fuel being converted into power, the balance going out the exhaust in the form of unburned gas or past the piston rings to contaminate the crankcase oil.

Certain engine or operating malfunctionings can exist which, at times, may cause the proper spark plug to be erroneously blamed for the trouble. The most common complaints are pinging, missing or sluggish performance and poor idling. Excessive spark advance or the use of gasoline with too low an octane number for the application may cause pinging due to detonation. This is usually most noticeable at low-speed, high-load operation such as accelerating up a hill.

Missing or sluggish performance may be due to many causes, primarily: improperly adjusted spark gap, retarded spark, lean mixture, and malfunctioning in the electrical system. Missing at low speed acceleration sometimes is due to a defective accelerating pump in the carburetor. Poor idling can be caused by poor valve seating, improper carburetion and plugged air filters.

It is a well-known maxim that a hot plug should be used in a cold engine, and a cold plug in a hot engine, but how hot or how cold a plug can be and perform satisfactorily depends upon the operating conditions involved. When a plug is too cold, carbon deposits form. It has been shown by several investigators that carbon will not remain on a surface heated above approximately 650°F. in an oxidizing atmosphere. It therefore, is desirable that the parts of the plug exposed to the combustion process be maintained above that temperature to keep carbon deposits at a minimum.

The absolute maximum plug temperature is limited by pre-ignition which is the uncontrolled ignition of the fuel-air mixture by the insulator tip or electrodes (or deposits thereon) heated to incandescence by combustion with ignition occurring before the accurately timed spark discharge. Any other part in the combustion chamber, e.g., exhaust valve, or deposits on the piston crown, will also cause pre-ignition if heated to a sufficient temperature.

The temperature at which an incandescent source will ignite the fuel-air mixture will depend upon many variables including nature of the fuel, mixture strength and pressure, and area and catalytic effect of the electrodes and heated surfaces as well

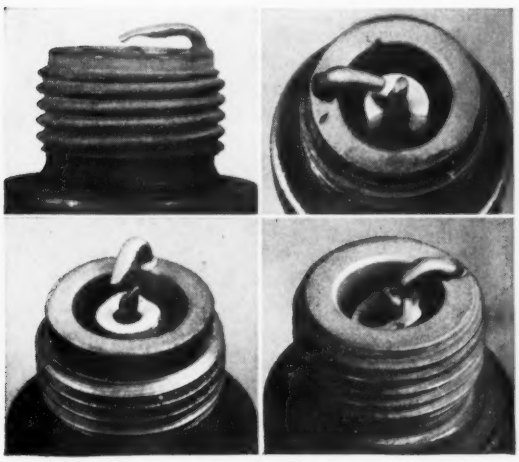


Figure 8 — Burned electrodes

Figure 9 — Aviation plug with fouled electrodes

Figure 10 — Fused lead deposits on ceramic nose

as any deposits which may be present in the combustion chamber. For a generalization, however, the temperature to induce pre-ignition is of the order of 1700-2000°F.

From the afore-mentioned limits, it can be seen that plug temperature should lie between 650 and 1700°F. At the higher operating temperatures, even before pre-ignition occurs, other factors become increasingly more important in limiting the operation, and in some cases may greatly reduce plug life. With the use of leaded fuels, electrode erosion and corrosion both increase with temperature; a plug that runs too hot tends to burn the points. Chipping, cracking or corrosion of the ceramic core nose also can occur. Optimum plug life, commensurate with peak performance, is reflected in the plug's ability to operate cool enough at high loads (and, accordingly, high temperatures) without causing pre-ignition or abnormal electrode or ceramic deterioration. In the very same installation, however, the plug must run hot enough to resist cold fouling or sooting under idling conditions.

Hotter operation seems to tend towards lessening deposits from fuels containing large amounts of tetraethyl lead. Plug design helps in this respect but is not the overall remedy for keeping deposit build-up to a minimum. Witness the heavy, lava-like deposit which shorted out the spark plug shown in Figure 9, taken from a commercial aircraft engine.

When the installed plug is the type recommended by the engine manufacturer and its appearance is indicative of over-heating it may reveal gas leakage or improper seating of the plug due to the condition of the spark plug gasket. The metallic gasket should be evenly compressed; if not compressed it will leak and interrupt heat flow to the water jacket. If flattened from previous over-tightening, it lacks resilience to sealing. An uneven color may indicate blow-by. In any case, if the gasket condition is at all questionable, it should be replaced.

Electrode burning, while a function of center electrode temperature, is also influenced by the nature of the electrical discharge, which in a conventional automotive ignition system is believed to consist of two different components: (a) the initial discharge which is controlled by the capacitance and resistance of the gap circuit; and (b) the subsequent decay of energy which is stored in the inductive fields of the ignition system. The initial discharge is a high-amperage unidirectional current discharge of short duration, and the remainder is a characteristic logarithmic decay of voltage considerably longer in duration, the initial stages of which are usually oscillatory in nature.

The initial spark ignites the fuel charge; the second portion, an "inductive discharge" is the result of energy inductively stored in the primary and secondary circuits and generally serves no purpose other than to burn the electrodes, as combustion is already under way. Some investigations, however, indicate the secondary discharge may have some effect upon the firing of extremely lean mixtures. The complete discharge characteristic may be graphically shown in Figure 11 as the line labelled "non-resistor plug."

Some plug designs, typical of which are those shown in Figures 5 and 12 overcome electrode burning by incorporating within the plug body a resistor which, although it has small effect upon the initial spark in the combustion chamber, does reduce the amperage level flowing through the discharge path, resulting in less heating of the electrode metal (at the strike point) with less metal sputtering and a subsequent increase in electrode life. The use of relatively large resistance values materially aids in reducing radio interference. The dotted line of Figure 11 represents the electrical discharge characteristics of a plug with an integral resistor.

At high temperatures, lead deposits are relatively good electrical conductors and, when a condition exists where glassy core nose deposits are formed, missing or complete shorting out can be expected. The data of Figure 13 show the great decrease in resistivity with increase in temperature for two of the lead compounds found in typical leaded fuel deposits, and reveal the fallacy of cold

electrical testing of aviation spark plugs which have been lead fouled by operation on high octane gasolines containing large amounts of tetraethyl lead. Even though a plug is heavily encrusted, an electrical check at room temperature may make the plug fire, while upon heating to 1200°F., for example, the electrical resistance of the fouling media is so reduced that the plug shorts out. This is a special case, however. The usual carbonaceous deposits on automotive spark plugs are not so "temperature sensitive"; cold checking may be adequate.

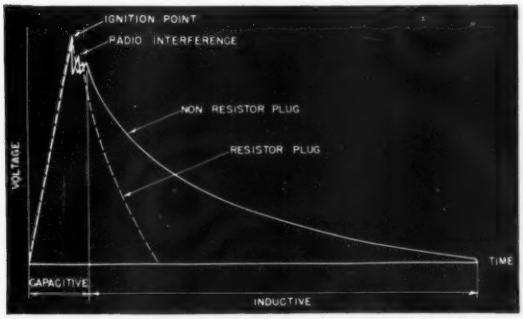
SPARK PLUG LOCATION

The location of the spark plug in the combustion chamber has a great effect upon the performance of the engine. As the location is fixed in existing engines it is of no concern to the average user; to the engine designer, however, it is of considerable importance.

For high-power performance a short but controlled burning time for the fuel is necessary, requiring a short flame travel. This can be accomplished by placing the plug as near as possible in the center of a combustion chamber which approaches a sphere in shape. This condition is reasonably satisfied in the hemispherical aircraft cylinder head where, by using two plugs, two flame sources are initiated which burn toward each other.

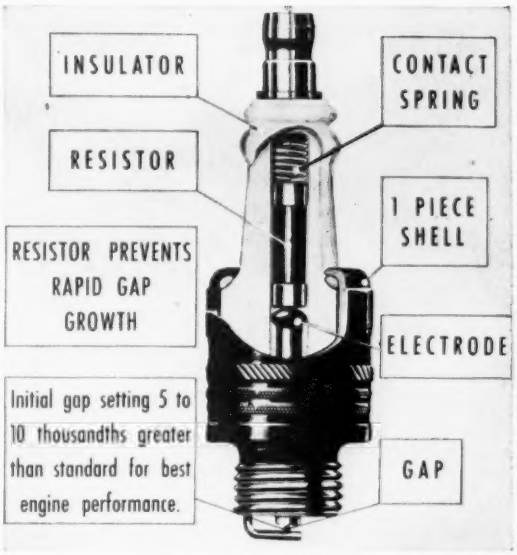
For good idling and high speed performance, a plug location near the intake valve is preferred, a location where there is a good combustible mixture regardless of stratification or dilution with burnt gases from the previous charge.

To minimize detonation, a plug location near the exhaust valve is advisable, which is usually the hottest region. This site is selected so that the flame front can advance into the cooler region of the combustion chamber. The pressure and temperature of the unburned charge increases during combustion, but the temperature increase would be considerably greater if compressed against a hot exhaust valve than against a cooler surface and, in the former case, detonation may result. To accommodate all these conditions, a compromise position between the intake and exhaust valves is frequently selected.



Courtesy of The Electric Auto-Lite Company

Figure 11 — Electrical discharge characteristics of a regular spark plug and a plug with integral resistor



Courtesy of The Electric Auto-Lite Company

Figure 12 — Automotive spark plug with integral resistor

GAS LEAKAGE

Under most types of operation modern plugs are very tight as far as internal gas leakage is concerned. Plug designs that can be disassembled may show leakage after overhaul if the sealing gasket was defective or not properly seated. A cracked insulator also may show leakage as will a plug with a defective seal between the center electrode and the ceramic or between the ceramic and steel shell. The effect of nominal leakage is negligible insofar as loss of compression pressure is concerned, but is of great importance in that it can alter the operating characteristics of the plug itself. Leakage carries hot gases, fuel soot, combustion residue, etc., up through the plug body and makes it operate hotter than designed. Fuel soot and deposits in the leakage path within the body may cause misfiring by forming a conductive track to ground.

Gas leakage in some plugs is revealed by a vertical, streaky sooting of the external, glazed insulator. When the insulator is generally dirty, however, care must be taken not to mistake a clean ring on the insulator just above the shell crimp to indicate gas leakage because the high dielectric strength of certain ceramics can cause a corona discharge to char the dirt from that area. Leakage can be determined by a standard spark plug tester or by screwing the plug into an adapter, immersing in water or kerosine, and applying air pressure. Bubbles immediately indicate a leak. Testing techniques

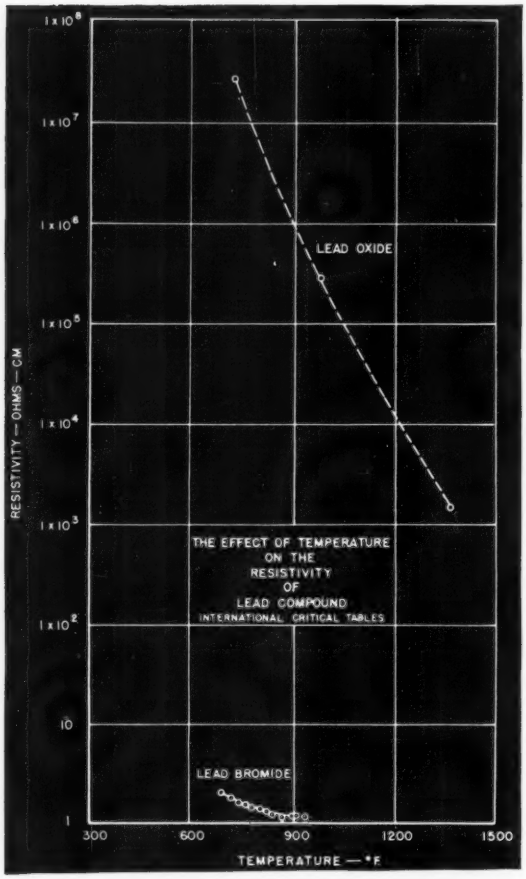


Figure 13 — From International Critical Tables National Research Council; Pub. by McGraw-Hill Book Co.

for aircraft plugs may use pressures up to 800 pounds per square inch.

SMALL TWO-CYCLE ENGINES

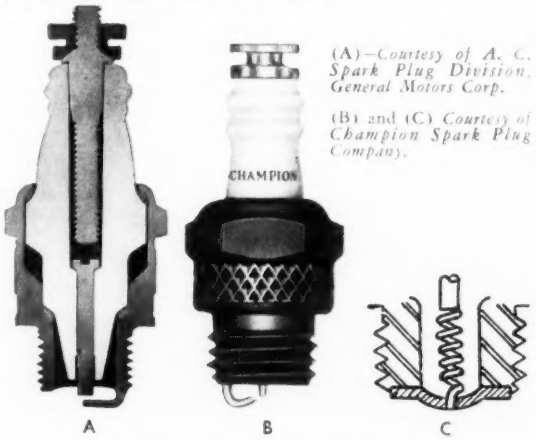
Small two-cycle gasoline engines, such as outboard marine engines, those used to power lawn mowers and small generators, as well as model airplane engines have a characteristic type of operation which requires special spark plug treatment. As these engines are lubricated by mixing the oil with the gasoline, a large proportion of oil finds its way into the combustion chamber and onto the plug. This necessitates careful selection of lubricant and fuel to minimize combustion chamber deposits for without that selection, the best of spark plugs will not perform satisfactorily. Highly refined oils with low carbon-forming tendencies are preferred. Certain residual oils and some additive-type oils generally leave more ash and deposit or carbon than distillate mineral oils or blends of distillate and well refined residual type oils. Some additive oils, however, do make cleaner-running engines. Therefore no blanket statement can be made on the effect of base stocks or additives: too much depends upon the specific components. White gasoline (unleaded) usually would be preferred for cleanest operation, but there are times, when the load conditions and temperature are such that leaded gasoline runs with less over-all deposits.*

When purchase of the necessary stocks must be made at the nearest service station, there are times when proper selection cannot be made; the best fuel and lubricant for automotive service may not necessarily be the best for two-cycle operation. The fuel is likely to contain appreciable amounts of tetraethyl lead, with one or more ash-forming additives in the lubricant. In this case, depending upon the type of service — light or heavy duty — different characteristic failure patterns may be expected for an extended operation. Light running, especially at time of starting, may lead to oil coking, causing plugs to misfire. Burning of the oil-laden fuel will create large amounts of soot. To accommodate this excessive sooting tendency, a plug operating hot enough to oxidize the carbon is required with a lean carburetor adjustment. When properly selected, a dry, clean plug, chocolate brown in appearance, can be expected.

Figure 14 (A) illustrates a typical outboard motor plug which has a long heat-flow path from the electrodes to the water jacket while, at the same time, its overall height is kept down for it to fit in the low overhead clearance space under the spray hood of the engine.

The model airplane engine, another two-cycle application, using mixtures as rich as one part heavy motor oil to three parts gasoline may run much hotter and heavier than its diminutive size suggests. In terms of IMEP or horsepower per cubic inch displacement some of these model en-

*The mechanism by which leaded-fuel combustion alleviates carbon deposits in two-cycle engines is not well understood. Some believe it due to a chemical interaction between the two; others hold that the impact of the lead compounds against the combustion chamber walls knocks off the carbon.



(A)—*Courtesy of A. C. Spark Plug Division, General Motors Corp.*

(B) and (C) *Courtesy of Champion Spark Plug Company.*

Figure 14 — (A)—An outboard motor spark plug (B) and (C) Details of model airplane plugs

gines may really be in the high output category, and relatively cold plugs can be tolerated.

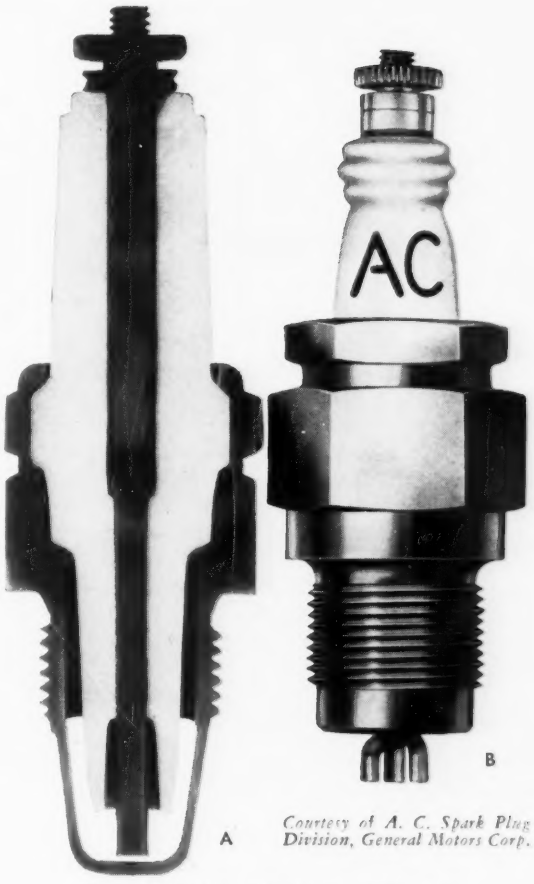
Figure 14(B) shows the smallest, commercially made model airplane plug, having a thread size of 1/4" x 32. Note the needle-like treatment of the ground electrode. The sharp point reduces the voltage required to produce a spark and makes easier firing on the sub-standard ignition systems.

Another variation in model airplane performance depends upon a sparkless self-ignition from an incandescent source, somewhat related to the uncontrolled effect, pre-ignition, which all other engine designs try to avoid for stable operation. As previously mentioned, if a region exists in a combustion chamber at a sufficiently high temperature, ignition of the fuel will take place without the necessity of an electric spark. These small engines maintain a hot spot by the use of a "glow plug", the firing end of which is shown in Figure 14(C), which is essentially a fine wire coil, frequently a platinum alloy, sufficiently thermally insulated that it will remain incandescent by virtue of the combustion surrounding it. To start the engine, a dry cell is connected to the plug until the coil becomes heated (as if it were a lamp filament). The current is continued until the engine runs.

For high load, steady running service such as driving farm equipment, pumps, generators, etc., for sustained periods sooting is relatively unimportant. Plugs, though, may encounter electrode erosion, and shorting out caused by a whisker-like deposit build-up bridging the electrodes. Accumulations of electro-conductive deposits on the electrodes can reduce the effective gap length and, due to the inherent construction of many flywheel-type magnetos, especially those in outboard marine engines, decreasing the plug gap length can overadvance the spark by as much as 50° creating a situation akin to preignition which may result in complete engine failure.

This unwanted early spark is believed due to the condition where, with a nearly-closed spark gap, the residual electrical energy in the system is sufficient to produce an additional spark at the plug gap when the interrupter closes, i.e., "makes", rather than when it "breaks" at the designated timing point.

Tendencies towards electrode bridging can be counter-acted to some extent by using a plug in which the end of the side electrode comes only to the center line of the center electrode [as shown in Figure 14(A)], rather than totally covering it as is commonly done in automotive practice (see Figure 3). With the off-set electrode, there is less masking of the spark by the electrode and less electrode surface is exposed for deposit accumulation. Furthermore, there is more opportunity for turbulence in the combustion chamber to keep the gap clean.



Courtesy of A. C. Spark Plug Division, General Motors Corp.

Figure 15 — (A)—A Diesel-type spark plug
(B)—A natural gas engine plug

OIL ENGINES

Spark plugs are used in certain types of small size, high speed Diesel engines to provide easy starting, especially in cold weather when the cranking effort is very severe on storage batteries. Such engines are so constructed that they can be temporarily converted from a normal, high compression, Diesel engine into a gasoline engine with carburetor, spark ignition and low compression. As the carburetor, manifold and ignition systems are designed specifically for starting only, this type of engine usually starts more easily than a regular gasoline engine of comparable size where power and economy are of major importance. Once running, the engine can be switched over to full Diesel operation; the "gasoline part" of the combustion chamber (containing the spark plug) is sealed off by a poppet valve.

Oil engines of the Hesselman type require a spark for controlled ignition. Such engines are frequently found in farm tractors, contractor's machinery and road patrol services where steady, high loads for long intervals are common. Tractor

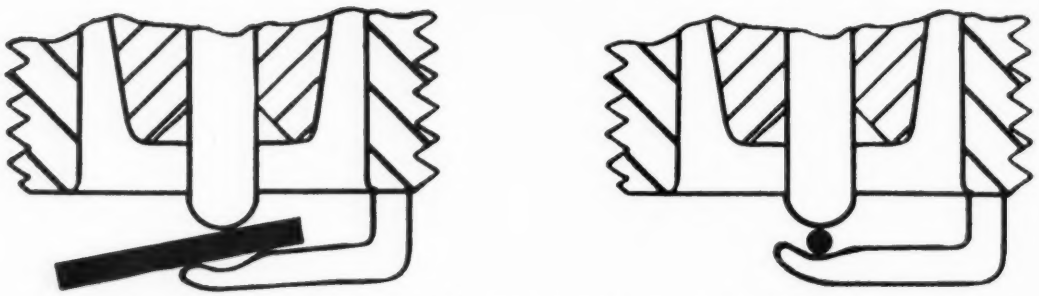


Figure 16 — Use of round feeler gauge correctly measures the gap width

fuel or diesel fuel is injected directly into the cylinder (same as for Diesel operation) where, from the heat of compression, it partially vaporizes. Combustion is initiated by the spark plug, usually at 10 — 12° before top dead center. To provide easier starting, gasoline is frequently injected into the intake manifold from a hand primer.

As a portion of the spray from the injected oil inadvertently wets the electrodes a special, hot-running, spark plug design is required, otherwise extreme sooting would result. Some styles are two-piece construction with a glazed insulator to facilitate "on-the-job" cleaning. The same type of plug which operates satisfactorily in the gasoline-starting Diesel usually will perform well in the Hesselman type. Figure 15(A) shows a typical oil engine or "Diesel type" plug where, from the electrode arrangement, it can be seen that it would operate considerably hotter than conventional automotive types. Due to its heat range and physical dimensions, it cannot be used in gasoline engines.

NATURAL GAS ENGINES

Heavy duty, slow speed engines burning either natural or artificial gas require a special plug capable of exceptionally long life, as it is not unusual for large units in central power generation and pumping service to run a year or more without interruption. Due to the inherent characteristics of natural gas which averages 60 — 90% or more methane, depending upon the source, some investigators report that substantially more energy is required for ignition than for other heavier hydrocarbon fuels of higher molecular weight, e.g., gasoline or Diesel fuel. The higher energy requirement would necessitate a fatter, hotter spark and, as such electrical characteristics would rapidly burn normal electrodes, a gas engine spark plug may have a large sparking surface, as can be seen in the plug illustrated in Figure 15(B). Some natural gas engines must also operate on raw gas containing appreciable amounts of sulfur. During combustion "sour" gas, as it is known, forms sulphurous acids which have a corrosive action on most engine parts including the plug electrodes. For such applications, the chemically-inert nature of the platinum electrode plugs have been well suited.

SPARK PLUG SERVICING

For maintaining peak plug performance, periodic inspections and checking are necessary. Spark plug cleaners marketed by the various plug manufacturers, in general, clean the firing ends by impingment of fine, dry, abrasive particles in a high pressure air jet. Usually five to ten seconds of "sand blast" are sufficient. Prolonged blasting wears away the electrodes and insulator as is shown by the uneven core noses of Figure 8; this affects heat characteristics. Lumps of hard carbon deposits can be easily removed from the steel shell with a wire brush or sharp knife. Care must be taken not to scrape the ceramic insulator with any metal such as a knife blade because the abrasive surface of the insulator can pick up a minute amount of metal, leaving a conducting track on the surface. Although scraping the center insulators is not so bad when they are glazed and smooth, the unglazed ceramics can pick up sufficient steel to cause misfire.

If the plugs are oily or wet, they should be first dried by a rinse in naphtha and an air jet before blasting because if wet, the abrasive granules will clog and do an inefficient cleaning job.

When the deposits are all removed, the gap should be reset, according to the manufacturer's specifications, by bending only the outside, ground electrode. During the adjustment of the side electrode, care must be taken not to accidentally apply any pressure against the center electrode, nor to attempt to adjust the gap by bending the center electrode as any strains may induce cracking of the insulator tip.

Gauging the gap width is best accomplished with a round wire feeler gauge, rather than a flat gauge. Worn electrodes frequently will be set too wide if a flat feeler gauge is used, although flat-dressed points are not affected. Figure 16 shows how a round wire gauge accurately checks the gap whereas a flat gauge, by improperly fitting the gap, gives a faulty measurement. In the illustration, the gap actually measures 50% greater opening than the flat gauge indicates.

Printed in U. S. A. by
Salley & Collins, Inc.
505 East 45th Street
New York 17, N. Y.

Greater Engine Efficiency

Use the oil that keeps engines clean Texaco Ursa Oil X**

Lower Operating Costs

You'll get more power, more efficiency, out of your heavy-duty gasoline and Diesel engines . . . and reduce your maintenance and operating costs at the same time . . . when you lubricate with *Texaco Ursa Oil X★★*.

Here's an oil that *keeps engines clean! Texaco Ursa Oil X★★* is fully detergent, dispersive and resistant to oxidation. It keeps rings free and valves active . . . protects parts against wear and bearings against corrosion. *Texaco Ursa Oil X★★* keeps your engines on the job longer between overhauls . . . keeps fuel costs low.

Texaco has lubricants for all your needs. Use them to assure both economy and improved performance. Just call the nearest of the more than 2300 Texaco Wholesale Distributing Plants in the 48 States, or write The Texas Company, 135 East 42nd Street, New York 17, New York.

TEXACO

REG. T.M.

TEXACO Lubricants and Fuels

FOR ALL CONTRACTORS' EQUIPMENT